Phenomenological models based on mixture configurations of magnetized D-branes

Keigo Sumita
(Waseda University, JSPS Research Fellow)

To appear with
Hiroyuki Abe and Tomoharu Horie

Introduction

- Magnetized brane model
- 10D SYM theory (D9-branes)
- Toroidal compactification with magnetic fluxes
- Superfield description
- 4D phenomenological model and (semi-) realistic flavor structures

- Mixture configuration (D5-D9 system)
- Some models and typical phenomenological features

D9 model (10D SYM)

- 4D N=1 decomposition

$$A_M = (A_\mu,\ A_i) \qquad i\ :\ 1,2,3$$

$$A_i \equiv -\frac{1}{\mathrm{Im}\tau_i}\left(\bar{\tau}_i A_{2+2i} - A_{3+2i}\right)$$

$$\lambda = (\lambda_0,\ \lambda_i)$$

$$V = \{A_\mu,\ \lambda_0\} \qquad \phi_i = \{A_i,\ \lambda_i\}$$

- Torus compactification

$$ds^2 = \eta_{\mu\nu}dx^\mu dx^\nu + \Sigma_i 2(2\pi R_i)dz^i d\bar{z}^{\bar{i}} \qquad z_i \equiv \frac{1}{2}\left(x^{2+2i} + \tau_i x^{3+2i}\right)$$

- zero-mode equation with magnetic fluxes

$$\bar{\partial}_{\bar{i}}\phi_j + \frac{1}{2}\left[\langle \bar{A}_{\bar{i}} \rangle, \phi_j\right] = 0 \quad \text{for} \quad i = j$$

$$\partial_i \phi_j - \frac{1}{2}\left[\langle A_i \rangle, \phi_j\right] = 0 \quad \text{for} \quad i \neq j$$

➡ Zero-mode wavefunction
(D. Cremades, L. E. Ibáñez and F. Marchesano)

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D9 model (10D SYM)

Gauge coupling constant	g	Dilaton	S
Torus areas	$\mathcal{A}_i = (2\pi R_i)^2 \mathrm{Im}\, \tau_i$	Kähler moduli	T_i
Torus shapes	τ_i	Complex structure moduli	U_i

$$\langle \mathrm{Re} S \rangle = \frac{1}{g^2} \mathcal{A}_1 \mathcal{A}_2 \mathcal{A}_3 \quad \langle \mathrm{Re} T_i \rangle = \frac{1}{g^2} \mathcal{A}_i \quad \langle \mathrm{Re} U_i \rangle = \mathrm{Im} \tau_i$$

$$S_{\mathrm{SUGRA}} = \int d^4x \sqrt{g^C} \left[\int d^4\theta C C^* \left(-3^{-K_{\mathrm{eff}}/3} \right) + \left\{ \int d^2\theta \left(\frac{1}{4} f_a \left(\Phi_m \right) \; W^a W^a + C^3 W_{\mathrm{eff}} \right) + h.c. \right\} \right]$$

$$-3e^{-K_{\mathrm{eff}}/3} = -3e^{-K_0/3} + Y_i \left(\Phi_m, \; \bar{\Phi}_m \right) \; \bar{\phi}_i \phi_i + \cdots$$

$$W_{\mathrm{eff}} = W_0 + \lambda_{ijk} \left(\Phi_m \right) \; \phi_i \phi_j \phi_k + \cdots$$

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D9 model (10D SYM)

Magnetic fluxes and Wilson-lines

- Gauge symmetry breaking

$$\langle A_i \rangle = \frac{\pi}{\mathrm{Im}\,\tau_i}\left(M^{(i)}\,\bar{z}_{\bar{i}} + \bar{\zeta}_i\right)$$

$$M^{(i)} = \begin{pmatrix} M_C^{(i)}\mathbf{1}_4 & & \\ & M_L^{(i)}\mathbf{1}_2 & \\ & & M_R^{(i)}\mathbf{1}_2 \end{pmatrix},$$

$$\zeta_r = \left(\begin{array}{cc|c|cc} \zeta_C^{(r)}\mathbf{1}_3 & & & & \\ & \zeta_{C'}^{(r)} & & & \\ \hline & & \zeta_L^{(r)}\mathbf{1}_2 & & \\ \hline & & & \zeta_{R'}^{(r)} & \\ & & & & \zeta_{R''}^{(r)} \end{array}\right),$$

$$U(8) \to SU_C(3) \times SU_L(2) \times U(1)^5$$

- Generation structure

$$\phi_i \sim \left(\begin{array}{cc|c|cc} & & Q & & \\ & & L & & \\ \hline & & & H_u & H_d \\ \hline u & \nu & & & \\ d & e & & & \end{array}\right)$$

ex) Q:

gauge quantum numbers : $(\mathbf{3},\ \mathbf{2},\ \frac{1}{6})$

zero-modes degeneracy : $\Pi_i(M_C^{(i)} - M_L^{(i)})$

$\Rightarrow$generarion

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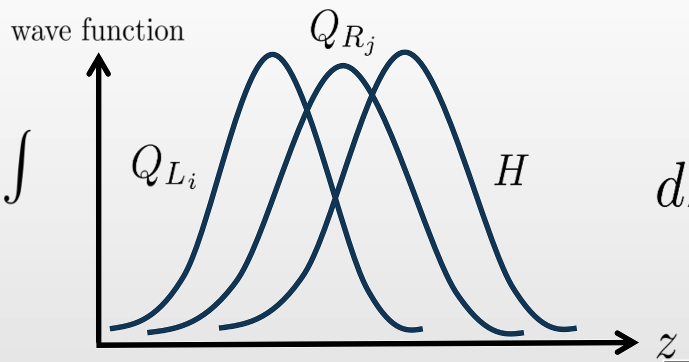
D9 model (10D SYM)

Zero-mode wavefunctions

- gaussian profiles by magnetic fluxes
- peak positions are shifted by Wilson lines

$$y_{ij} \sim \int \quad \cdots \quad dz d\bar{z}$$



y_{ij} can be hierarchical!

	Sample values	Observed
(m_u, m_c, m_t)	$(3.1 \times 10^{-3}, 1.01, 1.70 \times 10^2)$	$(2.3 \times 10^{-3}, 1.28, 1.74 \times$
(m_d, m_s, m_b)	$(2.8 \times 10^{-3}, 1.48 \times 10^{-1}, 6.46)$	$(4.8 \times 10^{-3}, 0.95 \times 10^{-}$
(m_e, m_μ, m_τ)	$(4.68 \times 10^{-4}, 5.76 \times 10^{-2}, 3.31)$	$(5.11 \times 10^{-4}, 1.06 \times 10^{-}$
$\lvert V_{\rm CKM} \rvert$	$\begin{pmatrix} 0.98 & 0.21 & 0.0023 \\ 0.21 & 0.98 & 0.041 \\ 0.011 & 0.040 & 1.0 \end{pmatrix}$	$\begin{pmatrix} 0.97 & 0.23 & \text{[illegible]} \\ 0.23 & 0.97 & 0.041 \\ 0.0087 & 0.040 & 1.0 \end{pmatrix}$

	Sample values	Observed
$(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})$	$(3.6 \times 10^{-19}, 8.8 \times 10^{-12}, 2.7 \times 10^{-11})$	$< \ 2 \times 10^{-9}$
$\lvert m_{\nu_1}^2 - m_{\nu_2}^2 \rvert$	7.67×10^{-23}	7.50×10^{-23}
$\lvert m_{\nu_1}^2 - m_{\nu_3}^2 \rvert$	7.12×10^{-22}	2.32×10^{-21}
$\lvert V_{\rm PMNS} \rvert$	$\begin{pmatrix} 0.85 & 0.46 & 0.25 \\ 0.50 & 0.59 & 0.63 \\ 0.15 & 0.66 & 0.73 \end{pmatrix}$	$\begin{pmatrix} 0.82 & 0.55 & 0.16 \\ 0.51 & 0.58 & 0.64 \\ 0.26 & 0.61 & 0.75 \end{pmatrix}$

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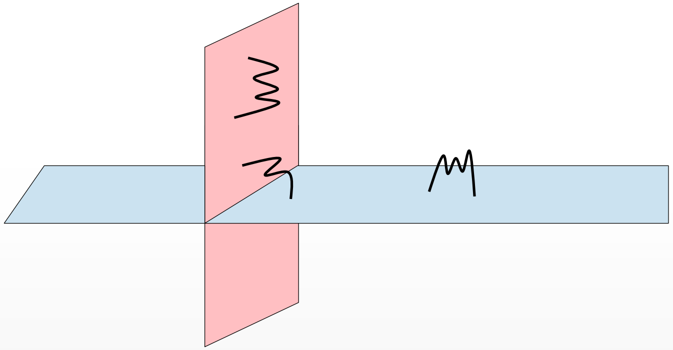
Magnetized D5 - D9 system

$$\int d^{10}x\sqrt{-g}\,\mathcal{L}_{D9}$$



$$\int d^{10}x\sqrt{-g}\left\{\mathcal{L}_{D9} + (\mathcal{L}_{D5} + \mathcal{L}_{5-9})\,\frac{\delta(z_i - c_i)}{\mathcal{A}_i}\,\frac{\delta(z_j - c_j)}{\mathcal{A}_j}\right\}$$

$\mathcal{L}_{D9}$: 10D $U(N)$SYM

$\mathcal{L}_{D5}$: 10D $U(N')$SYM

$\mathcal{L}_{5-9}$: ??

$U(N+N')$ SYM

$$\phi_i \sim \begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

Magnetized D5 - D9 system

Infinite Magnetic fluxes (D. Cremades, L. E. Ibanez and F. Marchesano)

- Infinite magnetic fluxes on 2nd and 3rd tori
- Localized as a point on 2nd and 3rd tori
- Chirality projection by magnetic fluxes

$$\phi_1 \sim \begin{pmatrix} A_1 & \\ & D_1 \end{pmatrix} \qquad \phi_2 \sim \begin{pmatrix} A_2 & B_2 \\ & D_2 \end{pmatrix} \qquad \phi_3 \sim \begin{pmatrix} A_3 & \\ C_3 & D_3 \end{pmatrix}$$

$$S_N^{SYM} = \frac{1}{g^2}\int d^4x \int d^6y \sqrt{-\det G}\Big[\left\{ \int d^2\theta \mathrm{Tr}\Big(\frac{1}{4}WW + \sqrt{2}e_1e_2e_3\epsilon^{ijk}\phi_i(\partial_j\phi_k - \frac{1}{3\sqrt{2}}[\phi_j,\phi_k])\Big) + h.c \right\} + 2h^{ij}\int d^4\theta \mathrm{Tr}\Big((\sqrt{2}\bar{\partial}_i + \bar{\phi}_i)e^{-V}(-\sqrt{2}\partial_j + \phi_j)e^V + \bar{\partial}_i e^{-V}\partial_j e^V\Big) \Big] + WZW$$

$$\mathcal{L}_{5_19}^{N^{(5_1)},N^{(9)}} = \int d^4\theta \mathrm{Tr}\Big(2h^{22}\bar{H}_2^{(5_19)}e^{-V^{(5_1)}}H_2^{(5_19)}e^{V^{(9)}} + 2h^{33}H_3^{(95_1)}e^{V^{(5_1)}}\bar{H}_3^{(95_1)}e^{-V^{(9)}}\Big) + 2\sqrt{2}e_1e_2e_3\Big[\int d^2\theta \mathrm{Tr}\Big(H_3^{(95_1)}(\partial_1 H_2^{(5_19)} - \frac{1}{\sqrt{2}}\phi_1^{(5_1)}H_2^{(5_19)} + \frac{1}{\sqrt{2}}H_2^{(5_19)}\phi_1^{(9)})\Big) + h.c\Big]$$

Phenomenological features

Model building

- ~~SUSY~~ sector
- More various flavor structures

~~SUSY~~ mediation mechanism

- Multi Moduli + Anomaly + Gauge
- Deflected mirage mediation

  (L. L. Everett, I.W. Kim, P. Ouyang and K. M. Zurek)

Model 1 D5 - D9
~~SUSY~~ MSSM

- The MSSM derived from only the D9-branes

  →embed the D9 model

- The ~~SUSY~~ sector on the D5-branes

  →more realistic models

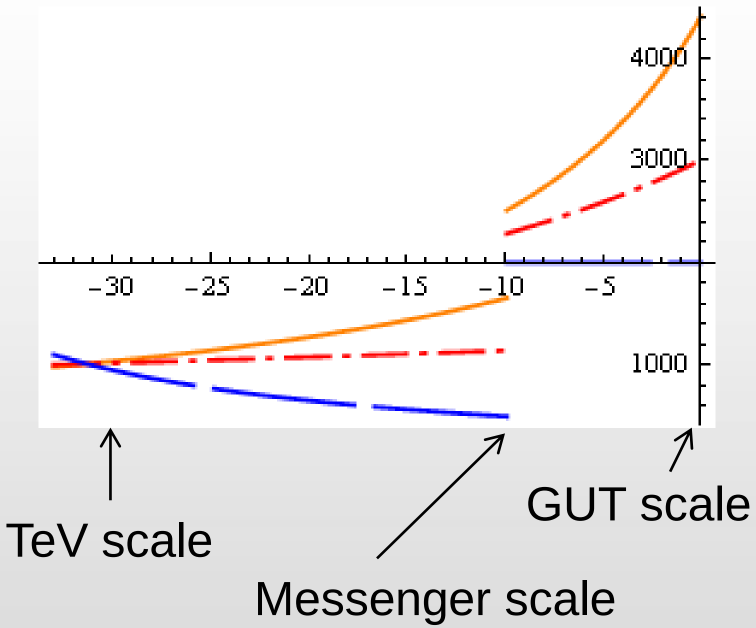
- The 5-9 modes as messengers or exotics

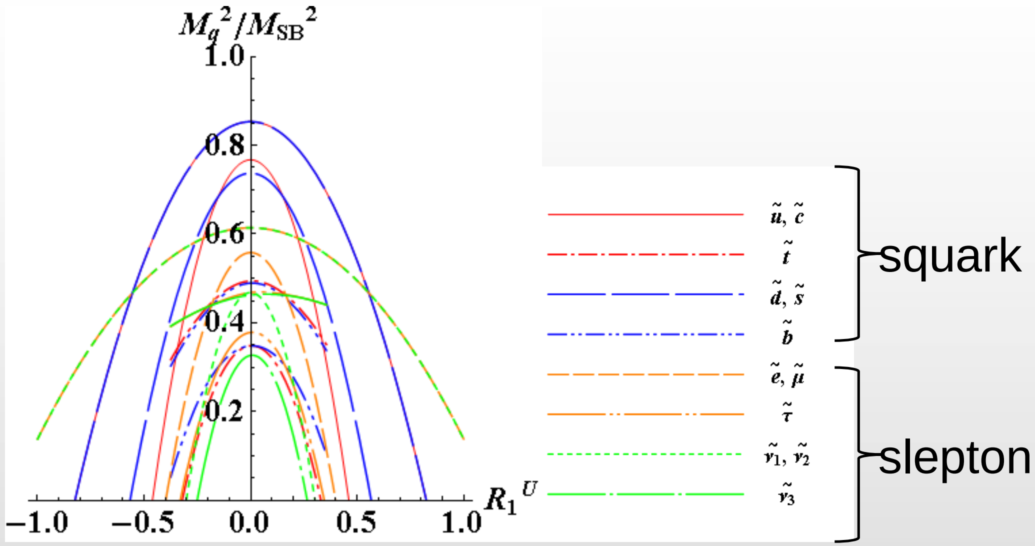
  →moduli, anomaly + gauge Mediation

A typical spectrum of superparticles

Deflected mirage mediation (L. L. Everett, I.W. Kim, P. Ouyang and K. M. Zurek)

$$M_{SB} = 2000\text{GeV},\ M_{mess} = 10^{12}\text{GeV}$$





- LSP,NLSP : neutralinos (975GeV, 994GeV)
- Supersymmetric flavor violations

Model 2 D5' - D5 - D9
~~SUSY~~ MSSM

- More various flavor structures
- Nonuniversal gaugino masses

	Gauge coupling constant		Gauge kinetic functions
D9	$\frac{1}{g^2} \times \mathcal{A}_1\mathcal{A}_2\mathcal{A}_3$	➡	S
D5	$\frac{1}{g^2} \times \mathcal{A}_i$		T_i

Model 3 D3 - D7
~~SUSY~~ MSSM

- Pure gravity mediation

Summary

- Generalization :10D magnetized SYM → magnetized D5-D9(or D3-D7) system
- Superfield description

  →4D effective SUGRA derived from magnetized D5 –D9 system
- Typical models and Phenomenological features